ASSESSMENT OF THE IMPACT OF THE PROPOSED SITE 170 PLACEMENT ISLAND IN UPPER CHESAPEAKE BAY

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Abstract

A three-dimensional (3D) hydrodynamic model of the upper Chesapeake Bay developed in a recent study to assess the impact of proposed dredged material placement islands on upper Bay circulation and salinity has been employed to assess the impact of two Site 170 Islands on the hydrodynamics of Baltimore Harbor. The major concern about such a placement island is its possible impact on the flushing of Baltimore harbor by upper Bay waters. Two islands were selected for investigation; namely a 40-million cubic yards (mcy) island and an 80-mcy island.

To aid in assessing the impact, the calendar years of 1992-1993 were selected for the simulation period. This period contains a wide range of environmental forcings including dry periods, large spring runoffs, and several extreme episodic events related to large set ups and set downs in the water surface of Chesapeake Bay.

In addition to comparisons of model results for salinity and currents in Baltimore Harbor with and without the placement islands, the water flux through the mouth of the harbor was computed to aid in the assessment of the impact of an island on the harbor flushing. Plots of current vectors averaged over selected periods were also generated to show the impact of the Site 170 Islands on residual circulation in Baltimore Harbor.

Model results show that residual velocities in Baltimore harbor are generally quite small, e.g., less than 1.0 cm/sec, and that the construction of either of the Site 170 Islands will not significantly change either the magnitude or the pattern of the long-term residual circulation. With the flushing time for existing conditions computed to be about 8 days, the flushing time for a 40-mcy will be only an hour or so greater and about 3-4 hours

greater for an 80-mcy island. A comparison of computed monthly-averaged salinities in Baltimore Harbor shows that the impact of the Site 170 Islands is to generally reduce salinity in the harbor.

Introduction

The Port of Baltimore, located on the Patapsco River in upper Chesapeake Bay, is managed by the Maryland Port Administration (MPA). The navigation channels of the port include the outer harbor channels consisting of the C&D Canal and Approach Channel, Tolchester Channel, Swan Point Channel, Craighill Channel, and Craighill Entrance channel (Figure 1). Maintenance and improvement of these channels, along with other navigation channels in Chesapeake Bay, coupled with the low availability of sites in which to place dredged materials, require proper management of existing sites and the development of long-term sites for placing material from future channel improvements.

With the capacity of existing dredged material placement sites in Chesapeake Bay being diminished, the MPA has determined the need for an upper Bay site for the placement of 4 mcy of dredged material each year for a period of 20 years, resulting in a cumulative placement demand of 80 mcy. To meet this demand, several potential sites for a placement island have been identified by the MPA.

A recently completed numerical modeling study by Johnson, et al. (1999) looked at the impact of several proposed dredged material placement islands in the upper Chesapeake Bay. That study utilized a 3D numerical hydrodynamic model called CH3D (Curvilinear Hydrodynamics in 3 Dimensions). The impact of each island focused on changes in upper Bay water volume containing a salinity less than several target concentrations, the upper Bay bottom area with salinities less than the target salinities, shear stresses in the navigation channels, and the location of the 1.0 ppt isohaline in the Tolchester Channel and the Chesapeake and Delaware (C&D) Canal Approach Channel.

At the completion of the study noted above, the MPA requested that the 3D numerical model be applied to asses the impact of an additional proposed placement island called Site 170 to be located near the entrance to Baltimore Harbor (Figure 2). The major concern about such a placement island is its possible impact on the flushing of Baltimore Harbor by upper Bay waters. Two islands were to be investigated: namely, a 40-mcy island and an 80-mcy island (Johnson et al. 2000).

Approach

The 3D numerical hydrodynamic model called CH3D was applied with and without each of the two Site 170 Islands. These islands were constructed on the same base numerical grid used in the previous study. There are a total of 6497 planform cells in the base grid. With a maximum of 20 layers in the vertical, the grid contains 27,064 computational dells. All vertical cells are 5-ft (1.52 m) except for the top cell, which varies with the tide.

The calendar years of 1992-93 were selected for the simulation period in the earlier island placement study. This period contains a wide range of environmental forcings including dry periods, large spring runoffs, and several extreme episodic events related to large set ups and set downs in the water surface of Chesapeake Bay. The same simulation period was selected for the model runs to assess the impact of the two Site 170 Islands.

The focus in the model runs presented herein was the impact of the Site 170 Islands on the hydrodynamics of Baltimore Harbor. In addition to comparisons of model results for salinity and currents in Baltimore Harbor with and without the placement islands, the water flux through the mouth of the harbor was computed to aid in the assessment of the impact of the islands on the harbor flushing. Plots of current vectors averaged over the averaging periods used in the Johnson, et al. (2000) study were also generated to show the impact of the Site 170 Islands on residual circulation in Baltimore Harbor.

Hydrodynamic Model

The basic model (CH3D) was developed by Sheng (1986) for the U.S. Army Engineer Waterways Experiment Station (WES), but was extensively modified by Johnson, et al. (1991). As its name implies, CH3D makes computations on a curvilinear or boundary-fitted grid. Processes impacting bay-wide circulation and vertical mixing that are modeled include tides, wind, density effects (salinity and temperature), freshwater inflows, turbulence, and the effect of the earth's rotation. The basic model exists in two versions that differ in the way vertical resolution is handled. One version makes computations in the vertical direction on a Cartesian grid, referred to as the z-plane version, where a different number of layers are used for regions of different depth. The sigma-stretched version makes computations on a stretched grid, which follows the bottom bathymetry with the same number of layers used throughout the grid. The z-plane version was employed in this study. Johnson, et al. (1991) provides theoretical details on the equations solved and the numerical algorithm employed in the basic model.

Model Forcings

The boundary conditions applied were the water surface elevation, salinity, and temperature at the southern boundary of the numerical grid; water flux, salinity, and temperature at the eastern end of the C&D Canal at Reedy Point; wind data from the Baltimore-Washington International Airport; freshwater inflows on the Susquehanna, Patapsco, etc Rivers; and surface heat exchange information computed from meteorological data collected at the Patuxent Naval Station on the Patuxent River.

Model Validation

Field data collected during Oct-Dec 1992 were used to validate the 3D numerical model. The first effort in the model validation was to demonstrate model reproduction of observed water surface elevations. Figure 3 shows a comparison of the observed water surface elevations at Baltimore, MD, with model results. It can be seen that both range and phasing are reproduced well. Similar results at other gages were computed.

The next effort in the validation process focused on demonstrating that the net flow through the C&D Canal, as reflected through a comparison of residual currents, was accurately reproduced by the model. Figure 4 shows a comparison of recorded and computed velocity near the middle of the canal at Station S3.9. It can be seen that normal tidal velocities are reproduced well and that generally velocities during episodic events (e.g., around 20-21 Oct) are also reproduced.

Taking an average of the velocity recorded at S3.9 over the two months yields a residual velocity computed by the model of 6.38 cm/s (0.31 ft/s) directed from the Chesapeake Bay toward the Delaware Bay. Similarly, the two-month average for the field data is 6.68 cm/s (0.22ft/s) directed toward the Delaware Bay. Thus, the model accurately computes the magnitude of the long-term net flow through the C&D Canal and its direction during this period. Computing the average canal velocity during the 20-21 Oct episodic event yields a model value of 54.04 cm/s (1.77 ft/s) and a field data value of 53.02 cm/s (1.74 ft/s). It can be seen that episodic events can result in large velocities in the canal that are unidirectional for several hours longer than normal.

The 3D model also computes salinity and water temperature. A comparison of model salinities with observed data during Oct-Dec 1992 are presented in Figure 5 at Station S3.9 in the middle of the C&D Canal. It can be seen that at times the computed and observed salinities agree quite well, whereas, at other times they can differ by 2-4 ppt. However, the proper response of the salinity to boundary forcings is always computed. In addition to the model computing the proper response of salinity to forcings, computed salinity averaged over periods such as a month compare quite well with the field data.

Hydrodynamic Impacts of Proposed Site 170 Placement Islands

The grid for the 80 mcy placement island is presented in Figure 6. The island extends above the water surface. Model runs were made without an island and then with a 40-mcy island and with an 80-mcy island. Each model run was for the full two-year simulation of 1992-93. To aid in assessing the impact of the two islands on hydrodynamic conditions in Baltimore Harbor, various types of model output were generated. These include monthly-averaged salinities and currents at several locations in Baltimore Harbor, instantaneous plots of water flux through the mouth of the Patapsco River and monthly-averaged statistics of those fluxes, and vector plots showing residual currents over several averaging periods.

Figure 7 shows the line across which the total time-varying water flux into and out of Baltimore Harbor was computed. This line is approximately the Rock Pt – North Pt Line shown in Figure 1. These computations were made each hour. Figure 8 is one of the monthly plots showing the water flux for the base condition and the difference between the base and each of the two proposed Site 170 Islands.

Although Figures 8 shows that the proposed islands can have an impact on the instantaneous flux of water passing into and out of Baltimore Harbor, they are misleading as far as showing the impact of an island on the flushing of the harbor. The reason for the relatively large instantaneous difference computations seen is due to phasing differences, as well as differences in the magnitude of the computed flux.

Table 1 presents the maximum flux into and out of Baltimore Harbor for the months of Jan-Aug 1992. In addition, the average flux for each month, as well as monthly average flux of upper Bay waters into the harbor are given. The later is a good indicator of the long-term flushing rate of Baltimore Harbor.

Table 2 shows monthly-averaged salinities and currents at the locations shown on Figure 4 for Mar 1992. It can be seen that at Point A the currents are impacted. This is to be expected since this location is very near the placement islands. However, at other locations in Baltimore Harbor away from the placement islands the impact of the islands on monthly-averaged water currents is insignificant. An inspection of Table 2 also shows that the impact of the islands on monthly-averaged salinities at the locations shown on Figure 7 is relatively minor. Some differences can be seen, but they are less than 0.5 ppt, with the impact of the islands generally resulting in a slight reduction in salinity in Baltimore Harbor. This is consistent with the computation of a slight reduction in the flux of upper Bay waters into the harbor.

Summary and Conclusions

A 3D numerical hydrodynamic model of the upper Chesapeake Bay developed to assess the impact of proposed dredged material placement islands on upper Bay circulation and salinity has been employed to asses the impact of two Site 170 islands on the hydrodynamics of Baltimore Harbor. Three model runs were made using the two-year simulation period of 1992-93.

During episodic events, the 40-mcy Site 170 Island results in reduction of about 10 % in the instantaneous values of the exchange of upper Chesapeake Bay waters with Baltimore Harbor, with even greater reduction for the 80-mcy island. However, these reductions are primarily due to differences in the phasing of the exchange computed with and without the islands in place, as well as magnitude differences. Since the magnitude of the average flux through the entrance into the harbor is not significantly changed by the islands, long-term flushing of the harbor with upper Bay water is not significantly impacted by the Site 170 Islands. With the flushing time for existing conditions computed to be about 8 days, increases in the flushing time for a 40-mcy island will be an hour or so and less than 3-4 hours for an 80-mcy island.

Model results show that residual velocities in Baltimore Harbor are generally quite small, e.g., less than 1.0 cm/sec, and that the construction of the Site 170 Islands will not significantly change either the magnitude or the pattern of the long-term residual circulation. A comparison of computed monthly-averaged salinities in Baltimore Harbor shows that the impact of the Site 170 Islands is to generally reduce salinity in the harbor.

References

Johnson, B.H., Kim, K.W., Heath, R.E., Hsieh, B.B., and Butler, H.L. 1991. "The Development and Verification of A Three-Dimensional Numerical Hydrodynamic, Salinity, and Temperature Model of Chesapeake Bay," Technical Report HL-91-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS

Johnson, B.H., Kim, K.W., Wang, H.V., Martin, B.L., and Heath, R.E. 1999. "Assessment of the Impact of Proposed Dredged Material Placement Islands in Upper Chesapeake Bay," Final Draft Prepared for Maryland Port Administration, US Army Engineer Research and Development Center, Vicksburg, MS

Johnson, B.H., Heath, R.E., and Kim, K.W. 2000. "Assessment of the Impact of the Proposed Site 170 Placement Island in Upper Chesapeake Bay," Final Draft Prepared for Maryland Port Administration, US Army Engineer Research and Development Center, Vicksburg, MS

Sheng, Y.P. 1986. "A Three-Dimensional Mathematical Model of Coastal, Estuarine, and lake Currents Using A Boundary-Fitted Grid," Report No. 585, A.R.A.P. Group of Titan Research and Technology, Princeton, NJ

Table 1. Monthly Flux Statistics

PERIOD	PLAN	MAX FLUX INTO HARBOR (CU/M/SEC)	MAX FLUX OUT OF HARBOR (CU/M/SEC)	MONTHLY-AVERAGE FLUX (CU/M/SEC)	AVERAGE FLUX INTO HARBOR (CU/M/SEC)
Jan 92	Base 40-mcy 80-mcy	6037 6269 6369	4472 4356 4201	-4.58 -2.26 -2.36	**607.6** **605.9** **598.4**
Feb 92	Base 40-mcy 80-mcy	3239 3285 3304	4298 4509 4661	-19.17 -19.26 -17.95	**576.2** **572.2** **566.1**
Mar 92	Base 40-mcy 80-mcy	3505 3401 3315	2950 2852 2794	-3.56 -3.92 -4.24	**581.6** **578.9** **274.4**
Apr 92	Base 40-mcy 80-mcy	3973 3965 3844	2859 2928 2975	-3.61 -5.30 -5.65	**618.6** **615.4** **608.8**
May 92	Base 40-mcy 80-mcy	3268 3154 3035	3166 3094 2974	-15.49 -16.58 -15.31	**606.5** **604.8** **600.2**
Jun 92	Base 40-mcy 80-mcy	3239 3165 3082	2896 2999 3304	-2.61 -3.71 -3.12	**647.4** **646.6** **642.3**
Jul 92	Base 40-mcy 80-mcy	4663 4403 4150	4542 4385 4115	-2.22 +1.28 -2.53	**670.0** **670.0** **662.2**
Aug 92	Base 40-mcy 80-mcy	4226 4166 4116	5215 5189 5033	-4.67 -4.71 -4.87	**662.8** **661.4** **656.6**

Table 2. Model Results for march 1992

STATION	PLAN	DEPTH	MEAN CURRENT (CM/S)	MEAN SALT (PPT)
A	Base 40 mcy 80 mcy	NS NS NS	-3.98 -5.22 -6.85	5.54 5.52 5.75
B	Base 40 mcy 80 mcy Base 40 mcy 80 mcy	NS NS NS NB NB NB	0.61 0.60 0.54 0.70 0.74 0.75	5.33 5.32 5.47 9.90 9.74 9.48
C	Base 40 mcy 80 mcy Base 40 mcy 80 mcy	NS NS NS NB NB NB	0.04 0.13 0.04 0.03 0.13 0.02	5.78 5.78 5.91 6.16 6.14 6.24
D	Base 40 mcy 80 mcy Base 40 mcy 80 mcy	NS NS NS NB NB NB	-0.65 -0.66 -0.70 -0.64 -0.65 -0.69	6.34 6.31 6.34 7.12 7.06 7.04

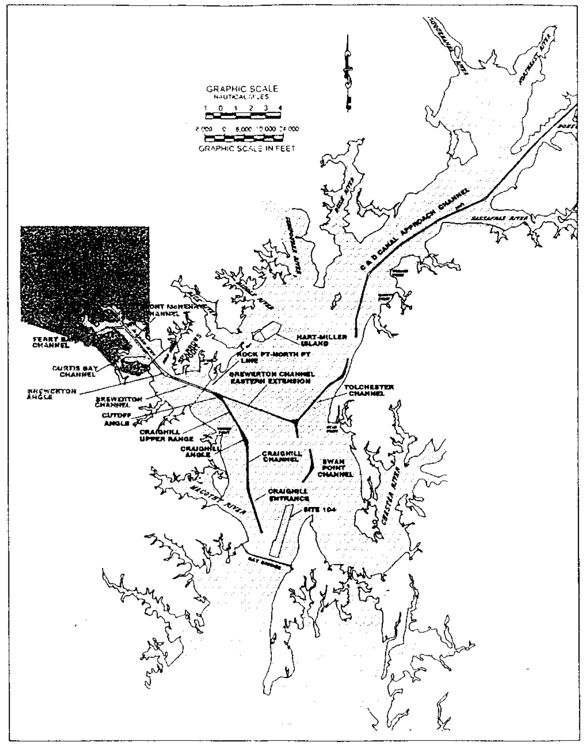


Figure 1. Upper Chesapeake Bay navigation channels

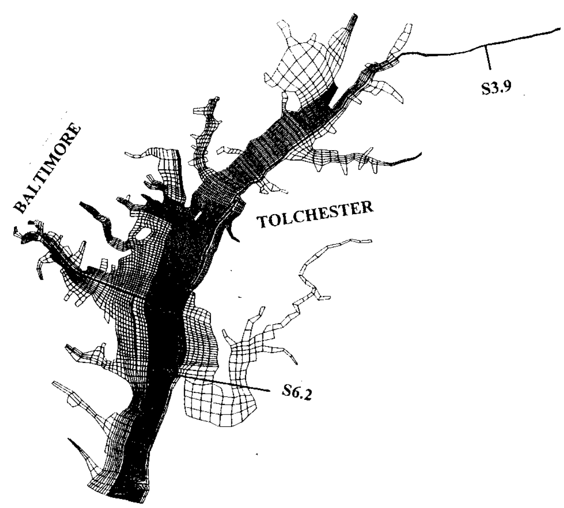


Figure 2. Base island placement planform grid.

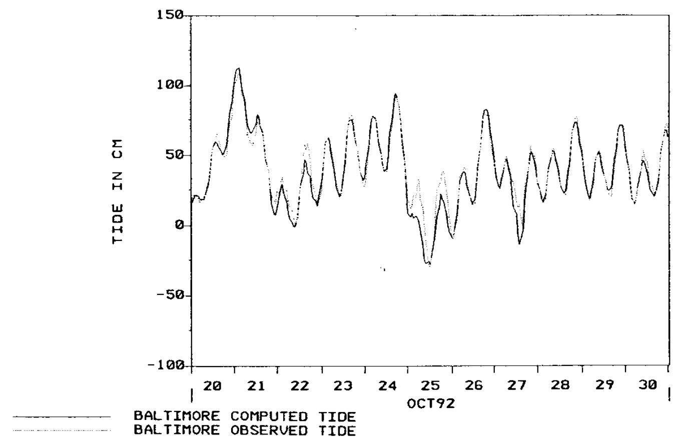


Figure 3. Computed vs observed WSE at Baltimore, MD

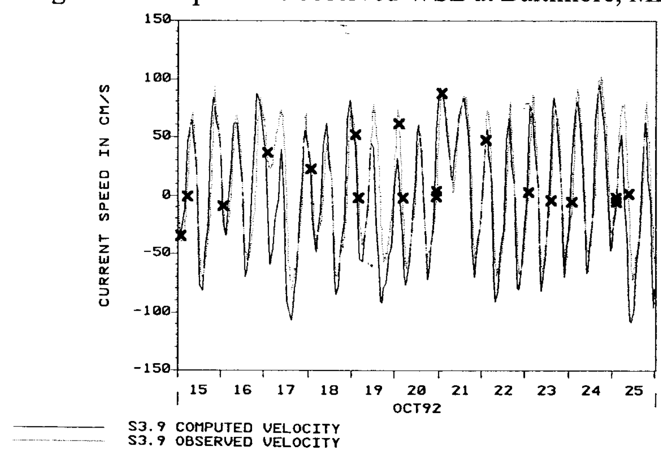


Figure 4. Computed vs observed velocity at S3.9

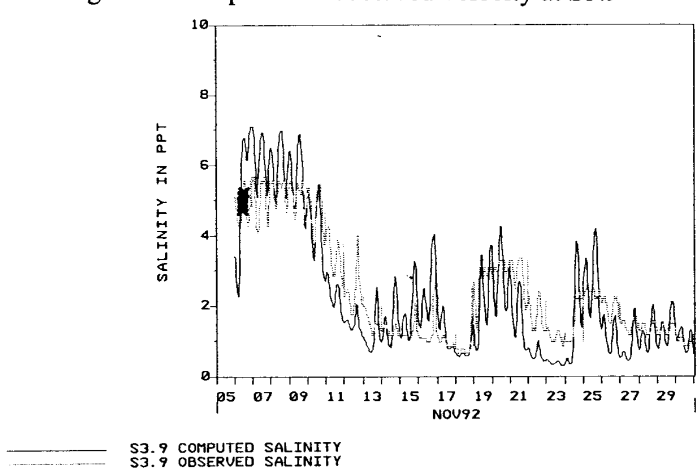


Figure 5. Computed vs observed salinity at S3.9

Figure 6. Planform grid for 80-mcy island

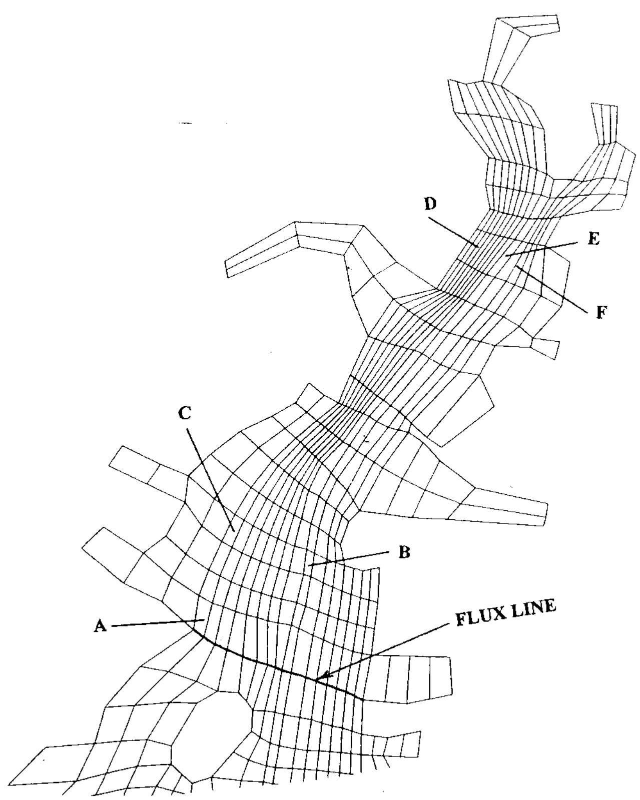
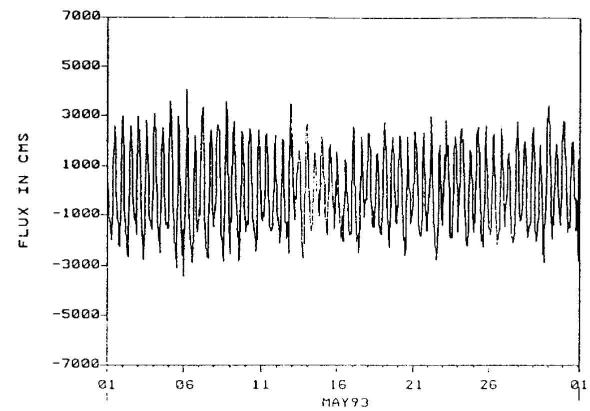
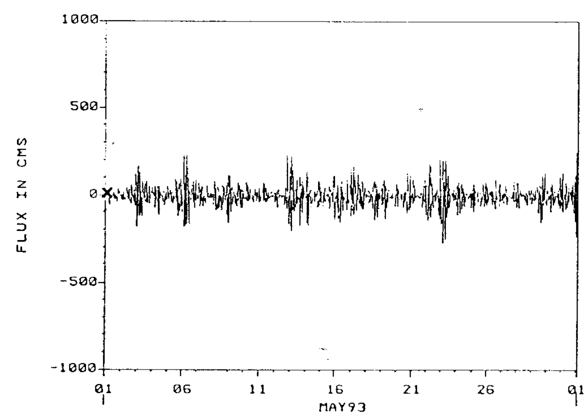


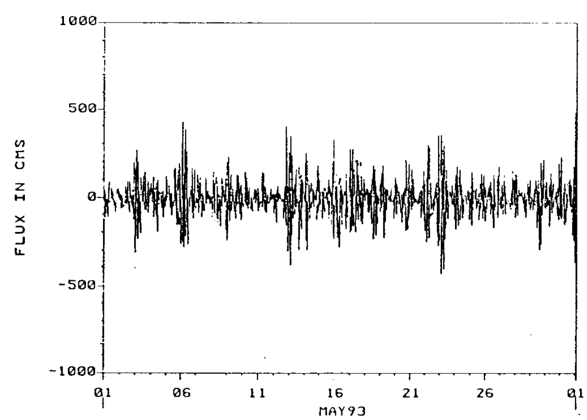
Figure 7. Location of computed results



a. Base



b. Base minus 40-mcy island



c. Base minus 80-mcy island

Figure 8. Baltimore harbor water flux during May 1993